Computer Graphics
MTAT.03.015
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Study IT in .ee
The Road So Far...

Last week:
- Construct geometry
  - Define transformations
  - Assign material properties

Vertex Transformations

This week:
- Vertex Shader
  - Object's local space → viewport space
- Culling & Clipping
  - Determine front-facing triangles
  - Determine which vertices are visible
- Rasterization
  - Fill the triangle with fragments
- Fragment Shading
  - Calculate correct color values
- Visibility Tests
  - Blend together multiple fragments
- Blending
  - Is the fragment visible?
Color

- What is color?
Color

- We represent color values with 3 channels:
  - Red
  - Green
  - Blue
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• The 4th (alpha-channel) is used for semi-transparent color values.
Color

- We represent color values with 3 channels:
  - Red
  - Green
  - Blue
- The 4th (*alpha*-channel) is used for semi-transparent color values.
- Values usually in ranges:
  - [0, 1]
  - [0, 255]
  - [0, FF]
Color

gl_FragColor = vec4(1.0, 0.2, 0.2, 1.0);

var color = new THREE.Color( 0xff0000 );

wuContext.fillStyle = 'rgba(255, 0, 0, 0.5)';
Do you believe that these are all red triangles?
RGB
RGB

- Subset of the visible color space
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- They see them using 3 types of cones with varying response rates in the eye.
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- Subset of the visible color space
- Humans see wavelengths roughly from 390 – 700 nm.
- They see them using 3 types of cones with varying response rates in the eye.
- *Infinite* amount of different colors.
There are actually many ways to specify colors in the computer (HSV, YCbCr, CMYK).
RGB

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- Also many different RGB color spaces (sRGB, Adobe RGB, Apple RGB, CIE RGB).
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- Also many different RGB color spaces (sRGB, Adobe RGB, Apple RGB, CIE RGB).
- Mostly we use the sRGB (standard) color space in graphics.
- But there is a catch...
Gamma Correction

- Do these seem of the same shade of gray?

Vertical black-and-white bars compared to sRGB color (128, 128, 128)
Gamma Correction

- The colors that the monitor outputs have your values passed through a function:

\[ \text{outputRGB} = sRGB^\gamma, \quad \gamma = 2.2 \]
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- This is because the old CRT monitors had a non-linear response rate (the function above).
- Thus a correction for this function was encoded in all media and has persisted to this day.
- Also it allows more different darker grays to be represented in sRGB.
Gamma Correction

• sRGB (128, 128, 128) gray is not exactly halfway between white and black when displayed.

• Imagine a fully red cube (255, 0, 0).

• If it is lit by a white light so that only 25% reflects off, what is the response we see?
Gamma Correction and sRGB

• Questions about sRGB, alpha channel, gamma correction?

• See if your monitor is calibrated correctly:
  http://www.lagom.nl/lcd-test/gamma_calibration.php

• More about gamma correction:

• About sRGB:
  http://dpanswers.com/content/tech_colmgmmt01.php
Lighting Models

• There are different types of light reflection, because there are different types of materials.
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- In computer graphics, basic lighting models include 3 distinct reflections / terms:
  - Ambient
  - Diffuse (Lambertian)
  - Specular (Phong, Blinn-Phong)
Lighting Models

- There are different types of light reflection, because there are different types of materials.
- In computer graphics, basic lighting models include 3 distinct reflections / terms:
  - Ambient
  - Diffuse (Lambertian)
  - Specular (Phong, Blinn-Phong)
- These describe a very basic lighting model. There exist more physically accurate ones.
Diffuse Reflection (Lambertian)

- We assume that light hitting a surface scatters in all directions equally.
Diffuse Reflection (Lambertian)

- So the amount of light reaching a viewer is independant of the viewer's position.
Diffuse Reflection (Lambertian)

- So the amount of light reaching a viewer is independent of the viewer's position.
- What about the light's direction?
Diffuse Reflection (Lambertian)

- What about the light's direction?
- Looking closer...
Diffuse Reflection (Lambertian)

- What about the light's direction?
- Looking closer...

Which surface looks more brighter for the viewer?
Diffuse Reflection (Lambertian)

- How much light reaches one surface unit?
Diffuse Reflection (Lambertian)

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Diffuse Reflection (Lambertian)

- Sine is difficult, can we calculate it with a cosine?
Diffuse Reflection (Lambertian)

Sine is difficult, can we calculate it with a cosine?

\[
\sin(\alpha) = \cos(90^\circ - \alpha) = \cos(\beta)
\]
Diffuse Reflection (Lambertian)

• How to calculate $\cos(\beta)$ knowing $l$ and $n$?

$n$ – surface normal
$l$ – direction vector towards the light source
Diffuse Reflection (Lambertian)

- This is the diffuse reflection term.

\[ I = n \cdot l \]
Diffuse Reflection (Lambertian)

• This is the diffuse reflection term.

• For a colored surface, we multiply it with coefficients $M \in [0, 1]$ for each color channel.
Diffuse Reflection (Lambertian)

- That is the diffuse reflection term.
- For a colored surface, we multiply it with coefficients $M \in [0, 1]$ for each color channel.
- For a colored light source we multiply it with coefficients $L \in [0, 1]$ for each color channel.

$$I = M \cdot L \cdot n \cdot l$$
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How much light reaches the surface

\( n \) – surface normal

\( l \) – direction vector towards the light source
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How intense is that light in RGB channels

\[ M \in [0, 1] \]
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How much the material reflects light in RGB channels

\( L \in [0, 1] \)
Ambient Light

- Describe these cubes...
Ambient Light

- Ambient light is almost always bouncing around.
- We add some small value of ambient light.

\[ I = M_{ambient} \cdot L_{ambient} + M_{diffuse} \cdot L_{diffuse} \cdot n \cdot l \]
Specular Reflection

• Is there something missing?
Specular Reflection

- Some surfaces seem more shiny
- That is because they will reflect some light directly, not scatter it in all directions
Specular Reflection (Phong)

- So, the surface should seem more brighter, if the light is reflecting directly into viewer's eye.
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $\mathbf{v}$ and the reflected light $\mathbf{r}$. 

\[ \mathbf{v} \cdot \mathbf{r} \]
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $\mathbf{v}$ and the reflected light $\mathbf{r}$. 
- Because that gives a too wide highlight, we also rise it to a power of shininess.

$$(\mathbf{v} \cdot \mathbf{r})^{\text{shininess}}$$
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $v$ and the reflected light $r$.
- Because that gives a too wide highlight, we also rise it to a power of shininess.
- Multiply also with the $M$ and $L$.

\[ M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess} \]

Check out CGLearn examples
Specular Reflection (Phong)

\[ \text{shininess} = 0 \]

\[ \text{shininess} = 30 \]

\[ \text{shininess} = 300 \]

\[ \text{shininess} = 90 \]
Phong's Lighting Model

- Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]
Phong's Lighting Model

- Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess} \]

The ambient term

Describes the indirect light all around the scene.
Phong's Lighting Model

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\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

The diffuse term

Describes the direct light that is diffusely scattered.
Phong's Lighting Model

- Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

The specular term

Describes the direct light that is specularly reflected
Phong's Lighting Model

- Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

Material's color is usually the same for both ambient and diffuse
Phong's Lighting Model

• Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess} \]

Material's specular color (tint) is usually white
Phong's Lighting Model

• Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess} \]

**Light's color** is usually the same for diffuse and specular
Phong's Lighting Model

- Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

Ambient light's color depends on the scene. Eg lot of red objects in the scene produce a red ambient light
Phong's Lighting Model

- Questions about ambient, diffuse, specular light?

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]
Shading

- Where to apply the light calculation?
- What points do we have in our geometry?
Shading

• Flat – apply it **per polygon**
• Gouraud – apply it **per vertex**, interpolate
• Phong – apply it **per fragment**

Diffuse lighting with flat, Gouraud and Phong shading models.
What was awesome today?

What more would you like to know?

Next time

Textures and Sampling